



A Review of Large Solid Rocket Motor Free Field Acoustics, Part I

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162nd Meeting of the Acoustical Society of America

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Background / Outline

At the ATK facility in Utah, large full scale solid rocket motors are tested. The largest is a five segment version of the Reusable Solid Rocket Motor, which is for use on future launch vehicles.

Since 2006, Acoustic measurements have been taken on large solid rocket motors at ATK. Both the four segment RSRM and the five segment RSRMV have been instrumented.

Measurements are used to update acoustic prediction models and to correlate against vibration responses of the motor.

Presentation focuses on two major sections:

- Part I) Unique challenges associated with measuring rocket acoustics**
- Part II) Acoustic measurements summary over past five years**





T-24 Test Stand

Year	Motor	Description
2007	TEM-13	Microphone array in far field (NASA, ATK, Wyle effort)
2008	FVM-2	Microphone array in far field (NASA, ATK, Wyle effort)
2008	FVM-2	4 microphones on a parallel path far field from motor
2008	FSM-15	Microphone array in far field (NASA, ATK, Wyle effort)
2010	FSM-17	Microphone sets on motor, 6ft, 30 ft from motor

T-97 Test Stand (*“hilly terrain”*)

Year	Motor	Description
2006	FSM-13	4 far field microphones on hillside
2007	FSM-14	4 far field microphones on hillside
2009	DM-1	4 far field microphones on hillside
2009	DM-1	Microphone arrays near and far field (with Dr. Kent Gee, BYU)
2010	DM-2	6 far field microphones at 4 locations (includes ground impedance measurements)

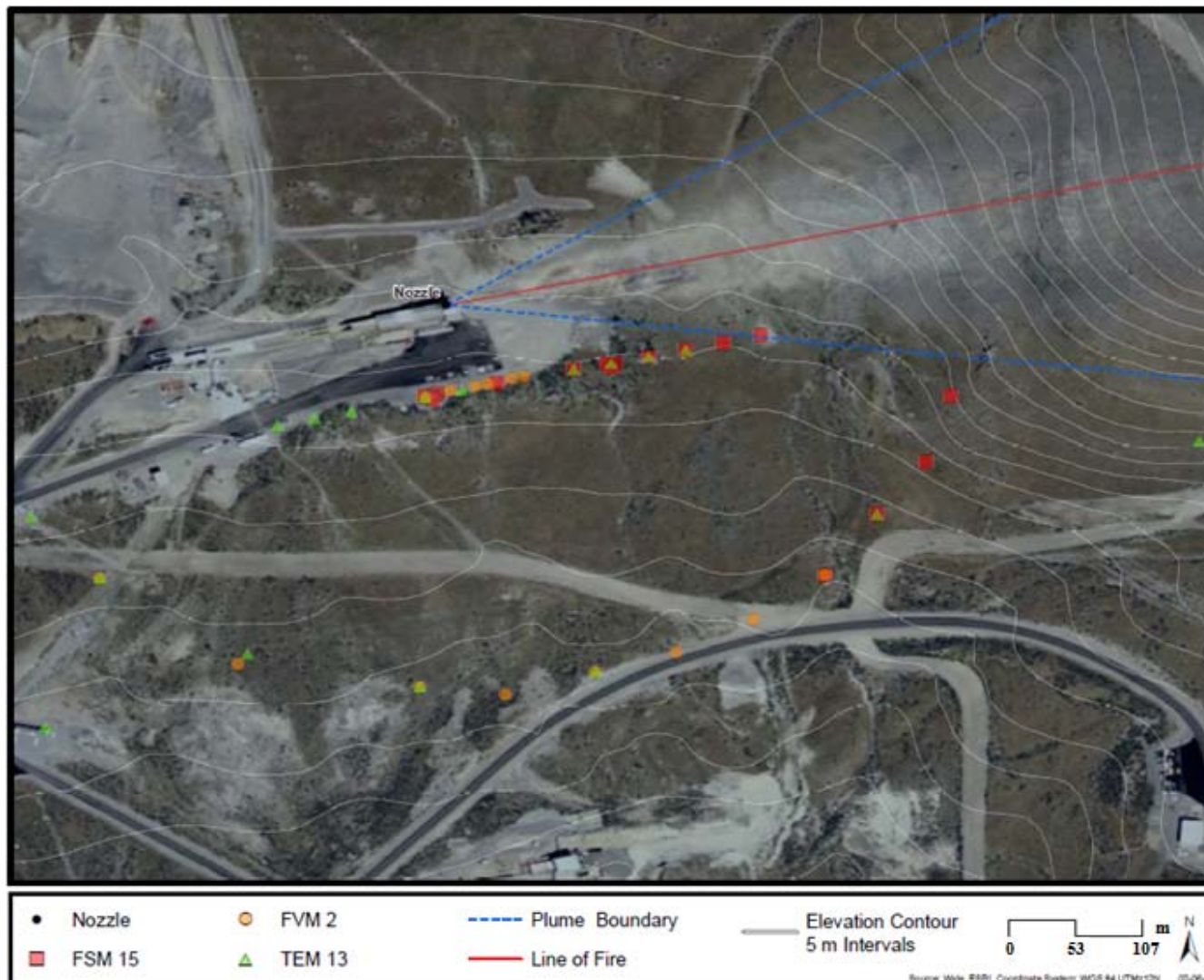


ATK Measurements

- Started with Endevco 8510B-5
- Now using 1/4" GRAS 40BD
- Data recorded at 100,000 samples/sec on a Genesis Recorder

NASA/ATK/Wyle Arrays

- 1/4" Microphones used for all locations
- Data recorded at 96,000 samples/sec on 24-bit system
- Wind, temperature, and relative humidity measured for corrections
- Ambient noise levels recorded



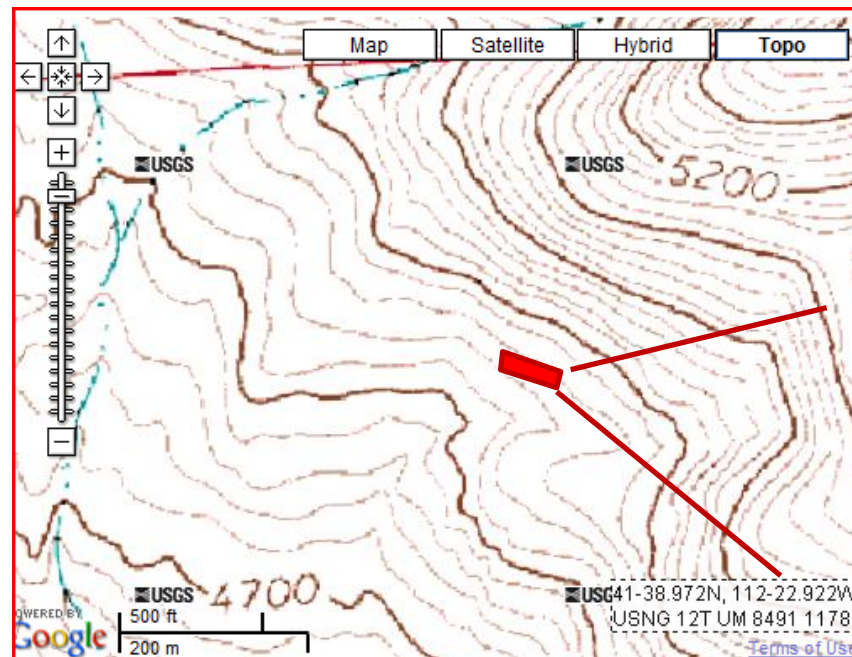


ATK/BYU Array of Microphones (T-97)



ATK/BYU





T-24 test site had flatter terrain / line of sight from microphone locations to motor plume compared to T-97

Several tests were run to evaluate T-24 and T-97 terrain effects on the measured data (Wyle Labs / ATK)

Additional tests were conducted to select best sensor type for this type of acoustic environment measurement (BYU / ATK)

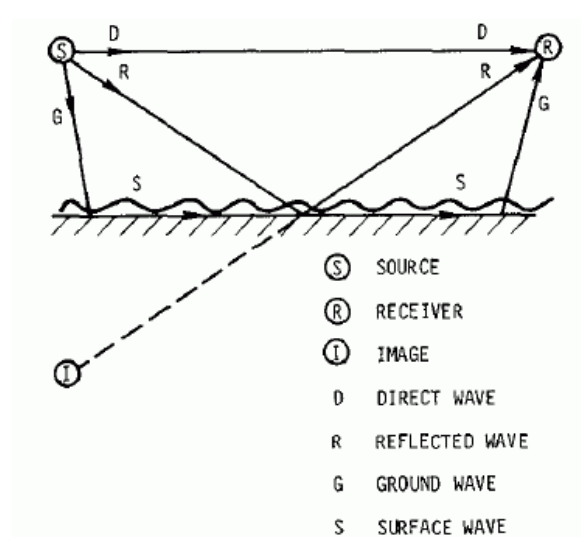
Ground Impedance Determination

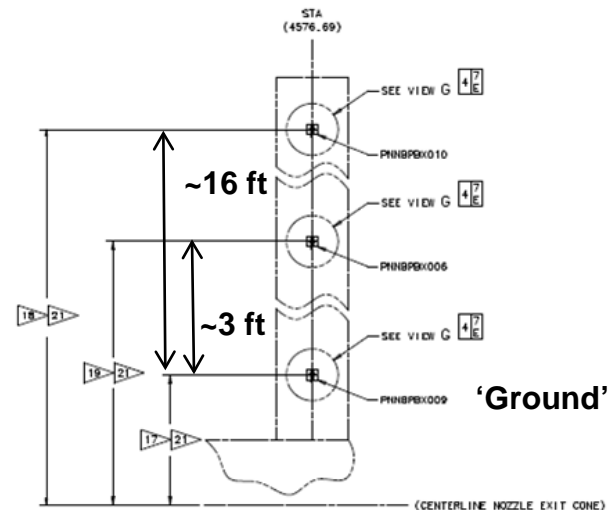
Wyle Labs measured the ground impedance from soil to aid in correcting out any propagating wave interference / reflection effects.

Followed ASA Standard, "American National Standard Template Method for Ground Impedance," ANSI S1.18-1999.

Uses multi-microphone method to measure broadband noise source wave reflections at different heights from the ground.

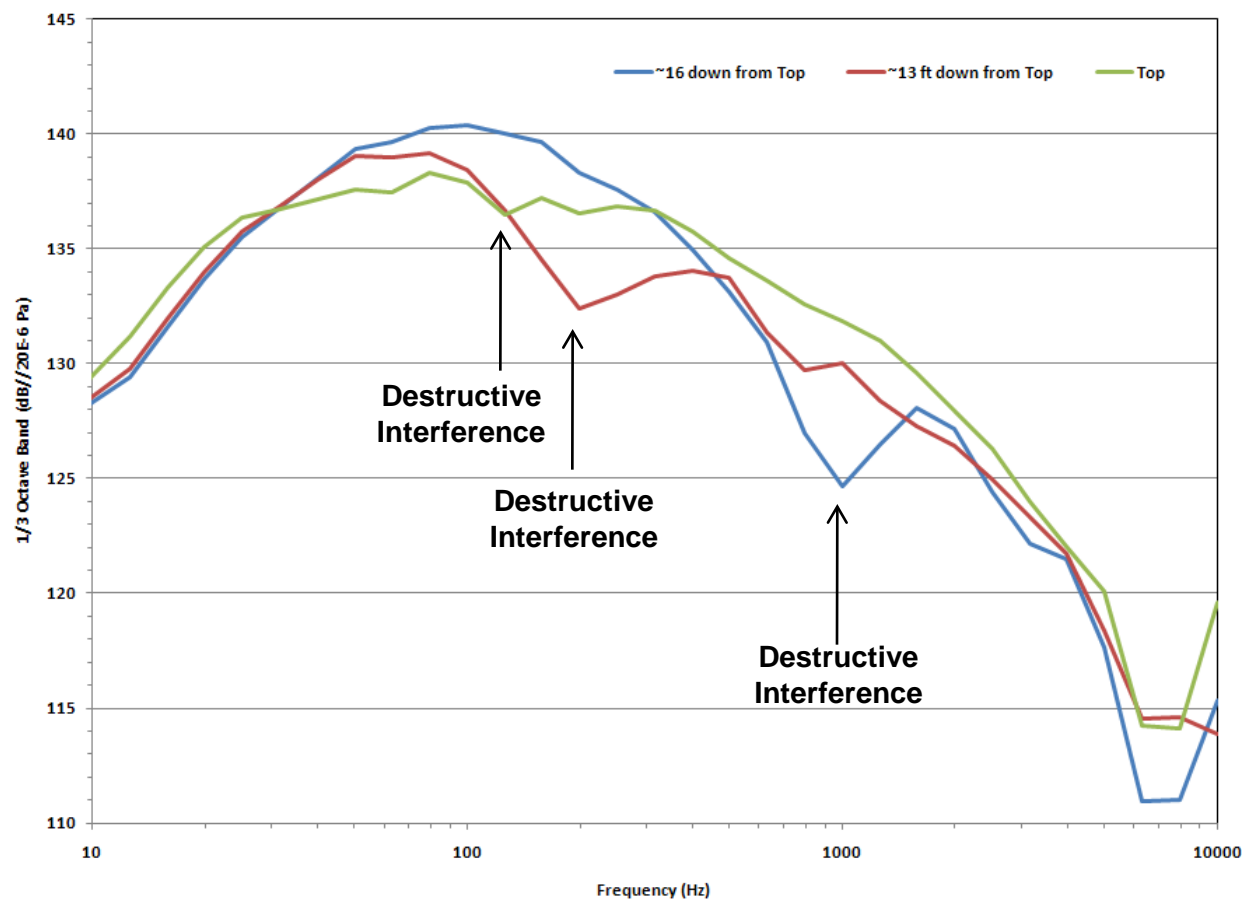
Ground impedance value is 160 rayls. Used for any correction models.





Three measurements taken at a fixed location at the T-97 test site.

Looking to see general terrain effect between three measurements during same test



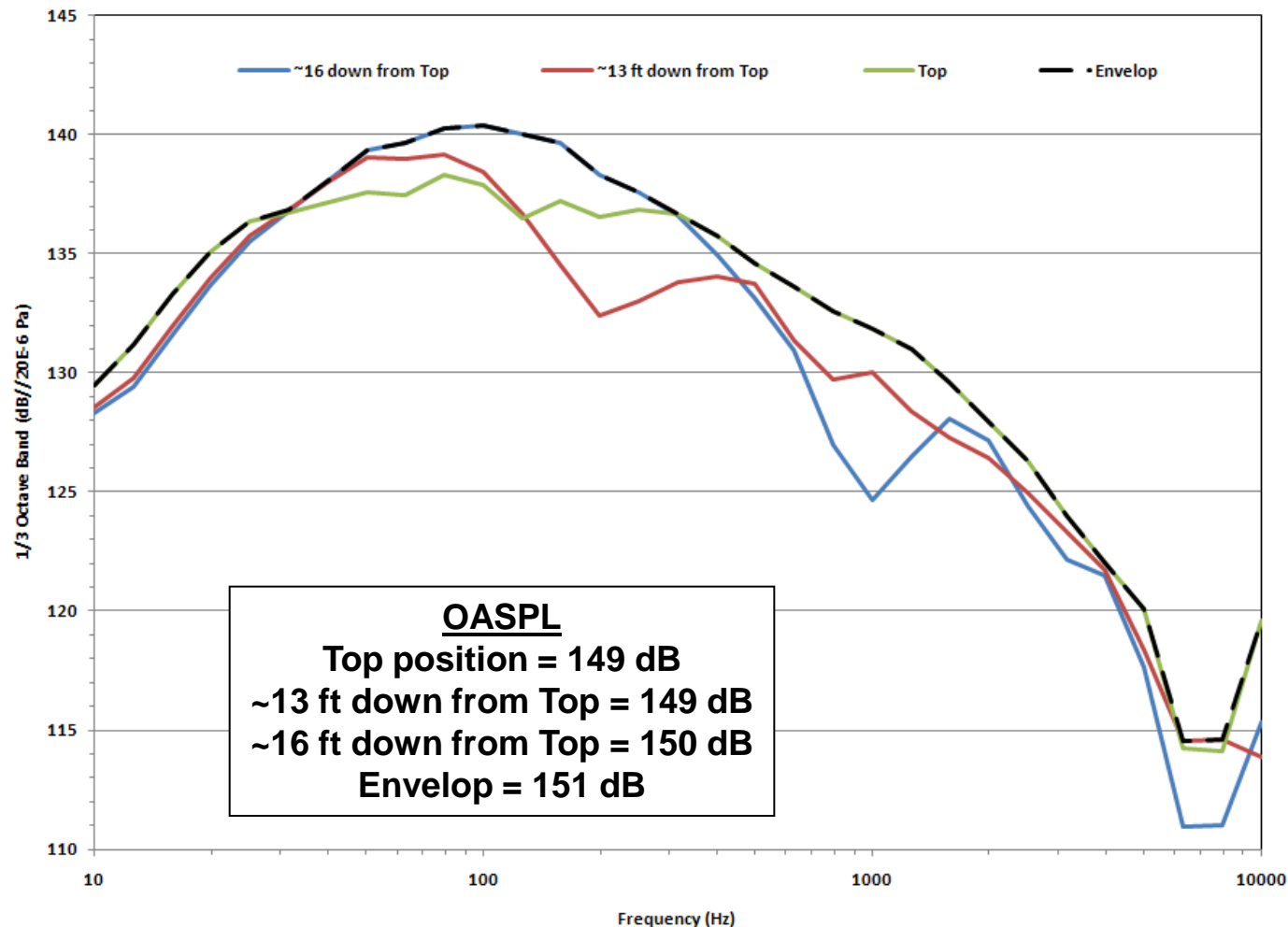


T-97 Acoustic Measurements – Varying Heights



Notable effect seen around 100 – 200 Hz, and 1000 Hz -> local effect only, no significant effect on OASPL

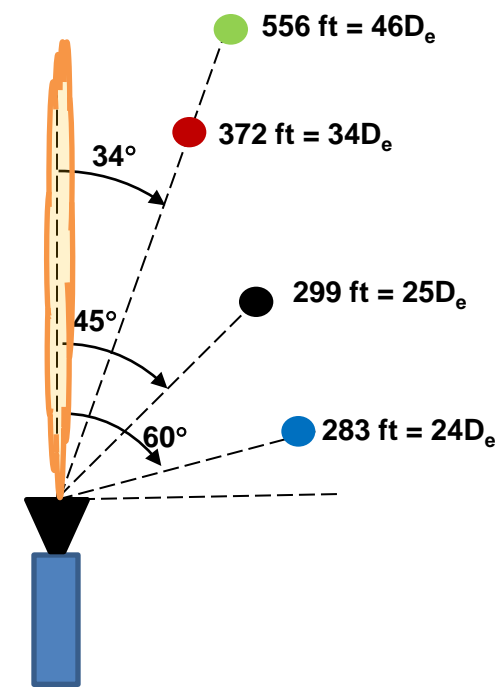
Simplest correction is to envelop octave bands to 'smooth out' the interference lines



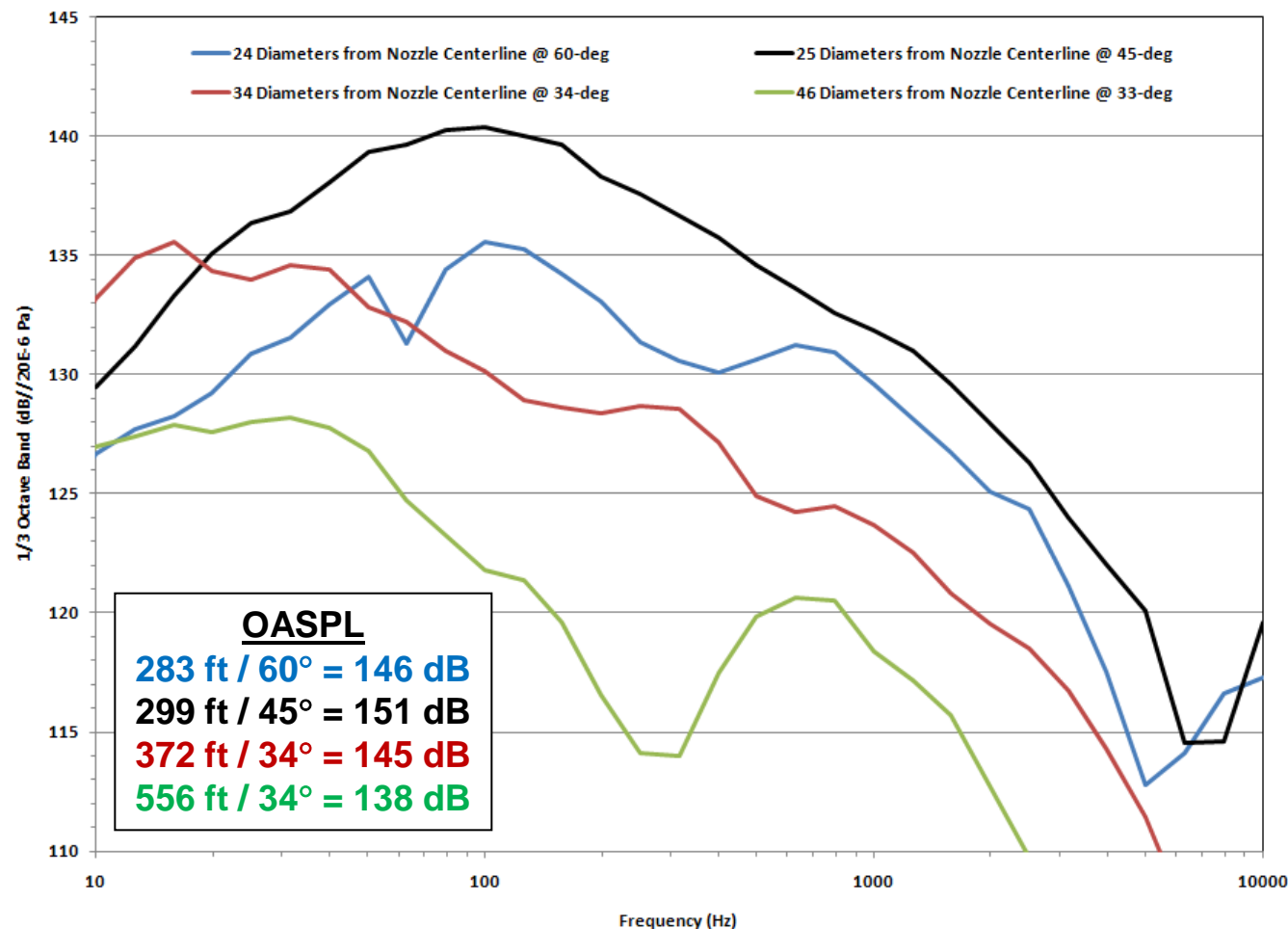
Interference effect seen in other locations

Need terrain effects model to better accommodate for the interference

Can still use OASPL values for comparisons against prior datasets



*Notional Schematic; Not to scale



Needed to select best microphone for high amplitude rocket acoustic measurements

Several options available, but ultimately two types were chosen for further study

- 1) GRAS ¼ " BH**
- 2) Endevco 8510B with variable vent tube lengths**

Study focused on side-by-side comparisons of GRAS and Endevco models at two separate firings, in addition to controlled lab work



GRAS 40BH

Vent tube length varied using attached tubing



Endevco 8510B-5

For this test objective, there were two arrays of instruments. One near the motor, and one far from the motor on a hillside. No instruments were positioned on the motor for this test.

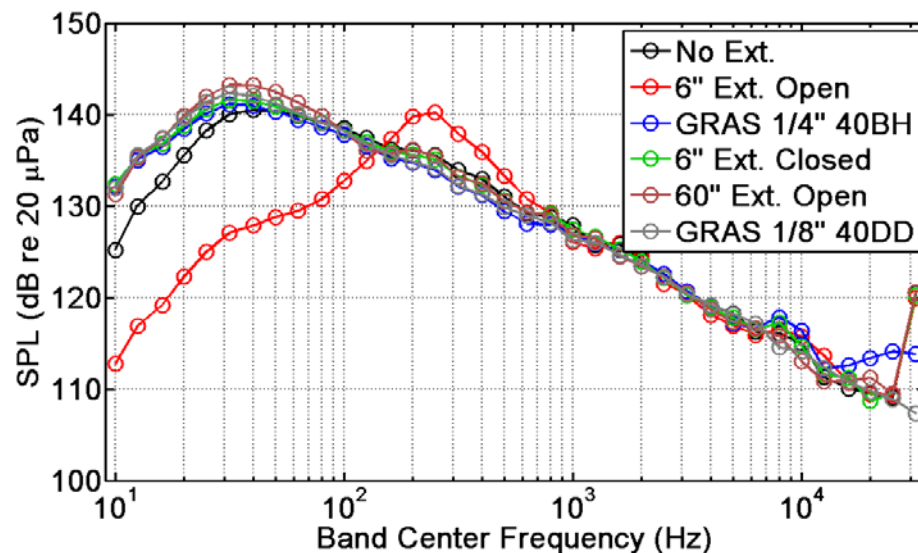


Hillside
measurements

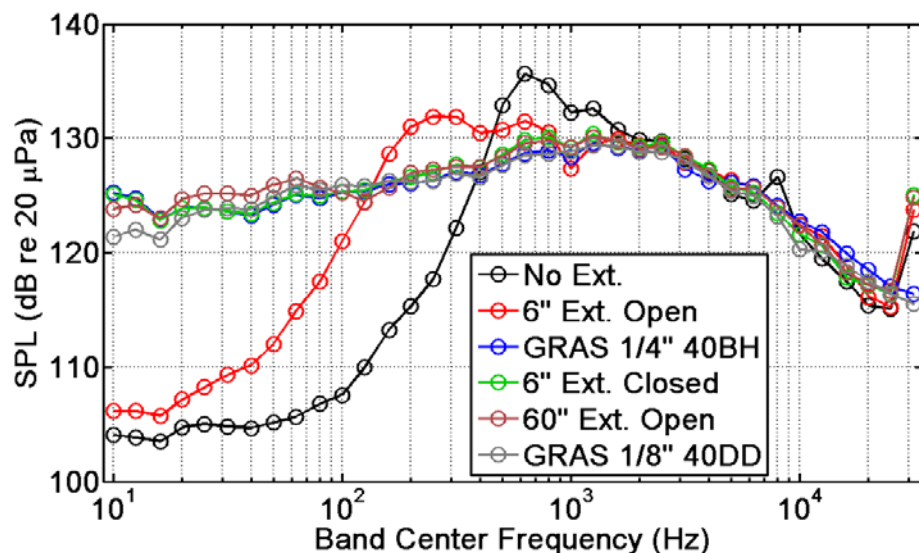
Near motor
measurements



Vent tube studies showed short open, or no vent tube extensions distorted data in low frequencies



Off Motor Array



Near Field Array

Best results came from GRAS 1/4" 40 BH responses, with 6" closed and 60" open vent tube responses being very similar



Ground Impedance = 160 rayls

Ground reflection interference causes notable spectral dB changes in the 100-200 Hz and 1000 Hz ranges

- Care should be used in comparing spectral content against previous data without ground effects model corrections
- OASPL less effected by ground effects

Choice of microphone sensor type and installation greatly effects measurements



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Acoustic data collected at two different test stands, T-97 and T-24.

T-24 test stand more amiable to free field acoustic data collection; T-97 had terrain complications addressed in Part I presentation

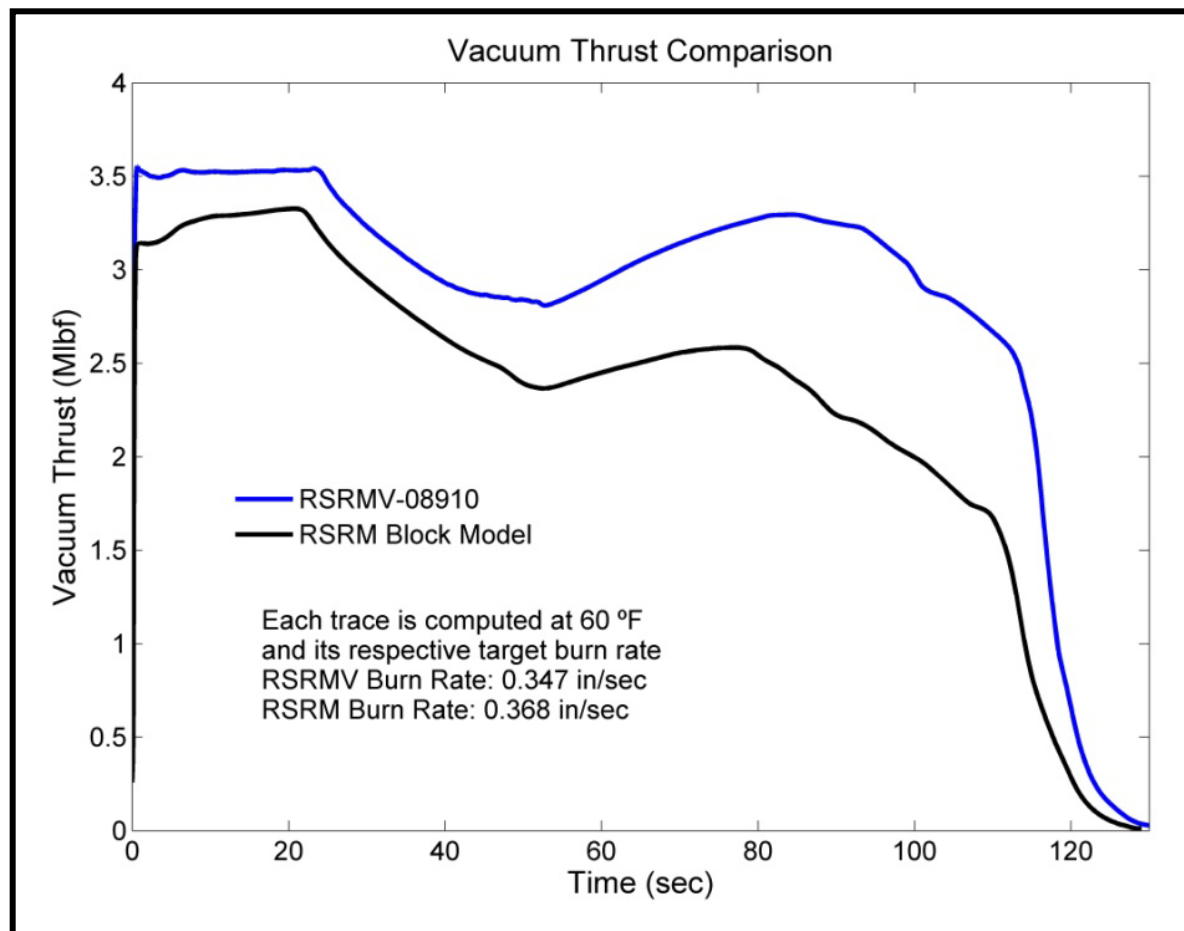
Part II focused on comparing the acoustic data collected between the two stands in terms of overall sound pressure levels (OASPL), spectral content, directivity, and relationship to motor operation





Thrust Profile for 4 and 5-Segment Rocket Motors **ATK**

- First stage five-segment rocket motor offers performance improvement over four-segment predecessor
 - Total Impulse: 368.1 Mlbf-sec
 - Maximum thrust (60°F/vacuum): 3.55 Mlbf
 - Web time average thrust (60°F/vacuum) : 3.13 Mlbf
 - Propellant weight: 1.385 Mlb
 - Grain geometry: 12 fin/CP
 - 56.86 in. diameter throat with 7.22 expansion ratio



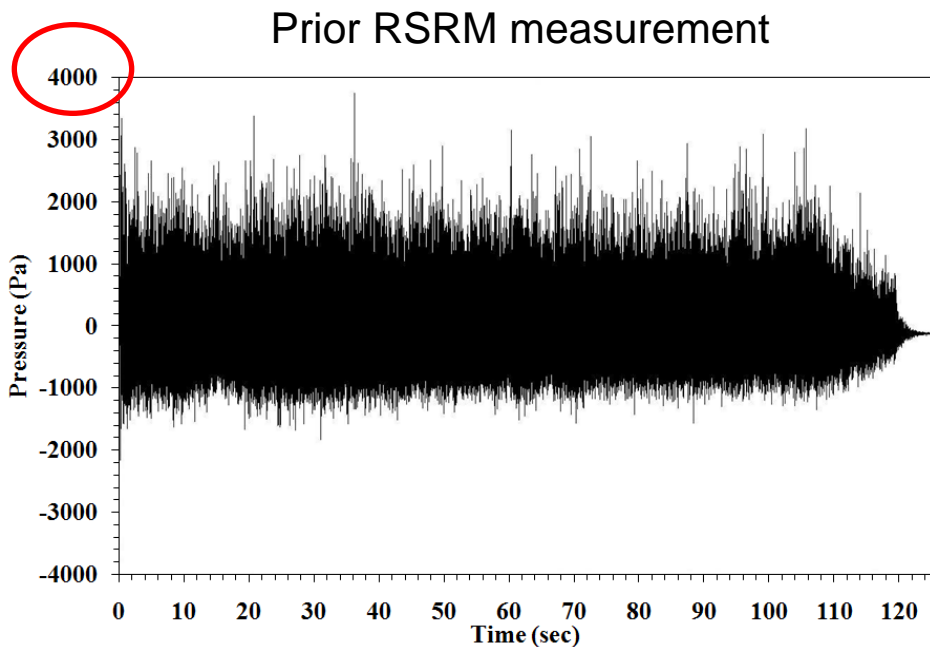
Reusable Solid Rocket Motor = RSRM (4-segment)

Reusable Solid Rocket Motor V = RSRMV (5-segment)

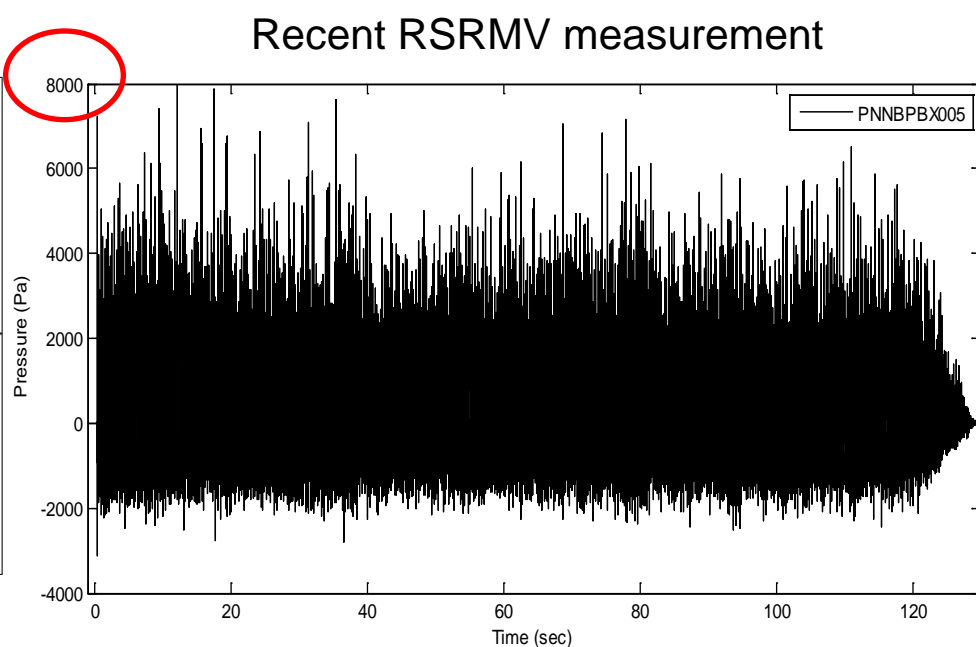
Example Time Histories

Positive skewness of data

Potentially due to plume shock contributions



17 nozzle diameters
and 90° from nozzle exit plane
T-24 Test Stand



24 nozzle diameters
and 60° from nozzle exit plane
T-97 Test Stand



4 vs 5 segment motors

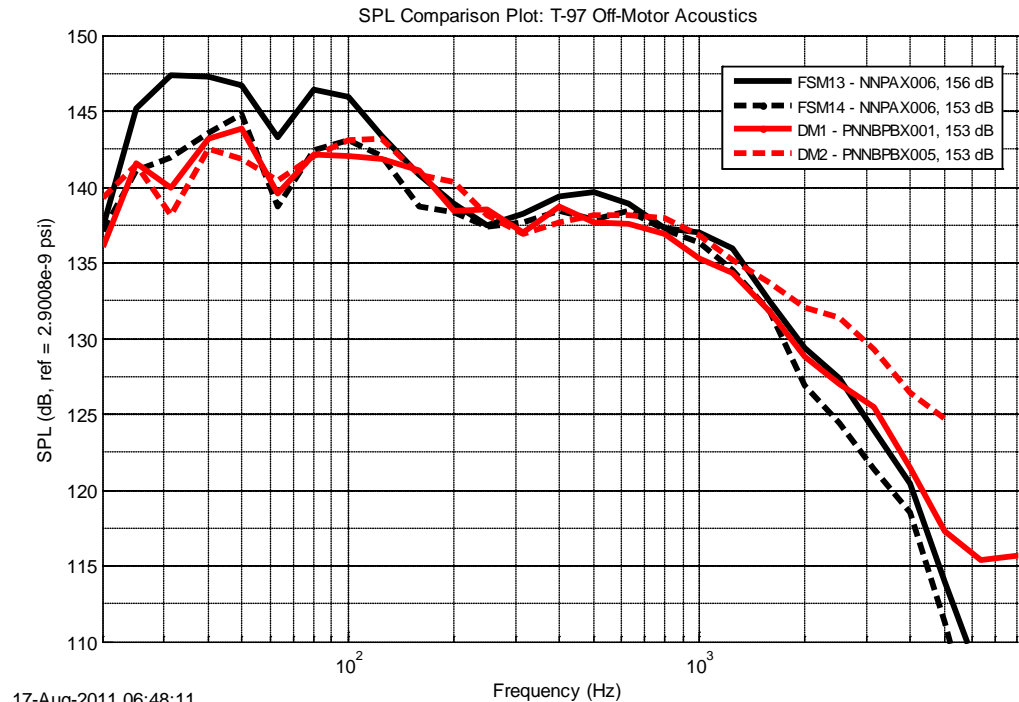


Generally, the four and five segment motors have similar external acoustic characteristics.

While the measurements in the figure were taken at the same location test-to-test, the distance from the motor changed slightly between four and five segment motors.

4 segment: exit plane plus 171 ft

5 segment: exit plane plus 144 ft



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-(Black) 4 segment motor
measurements from two tests
-(Red) 5 segment motor
measurements from two tests

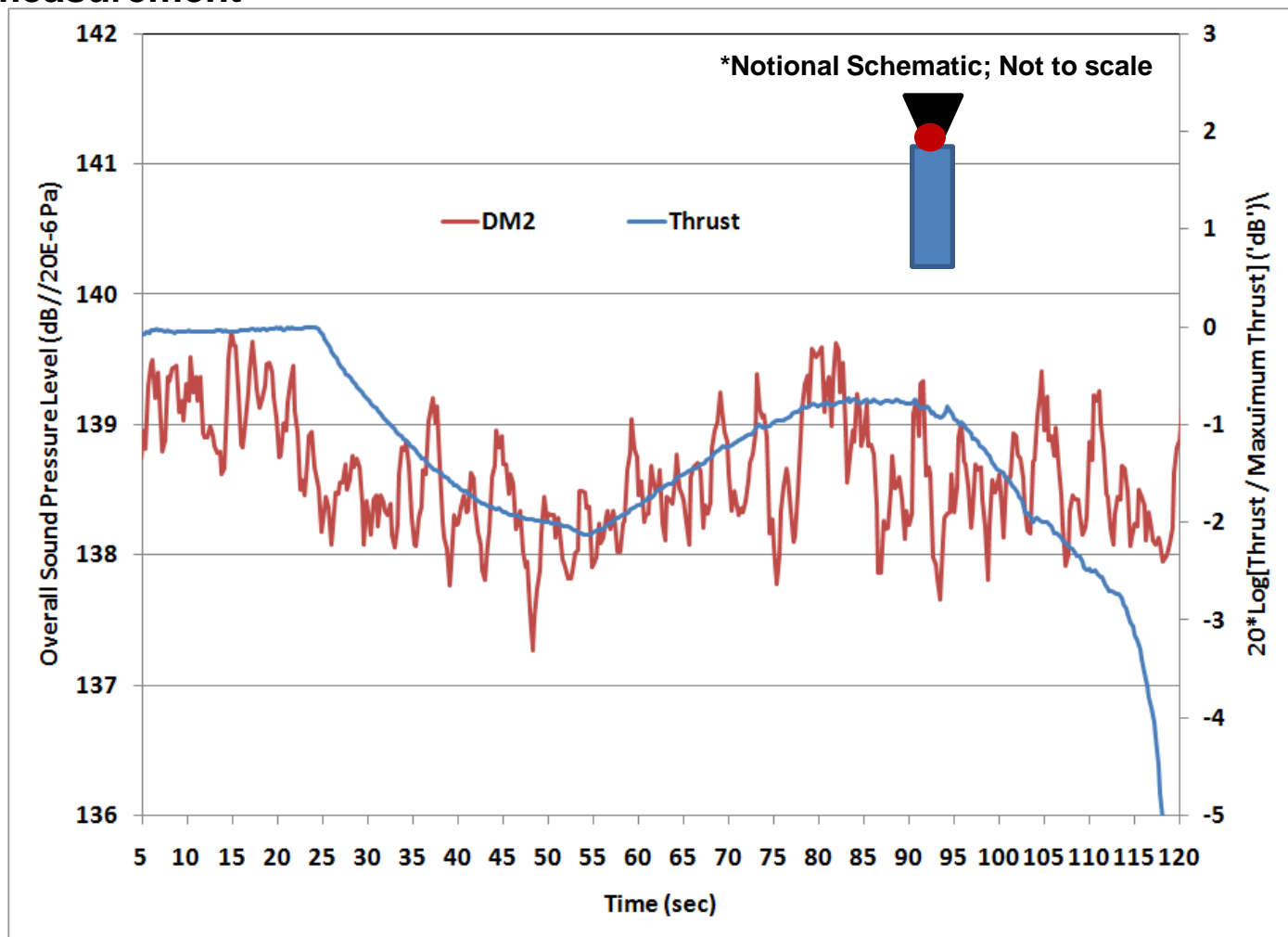


DM-2 Thrust Effects Throughout Test (Aft Dome)



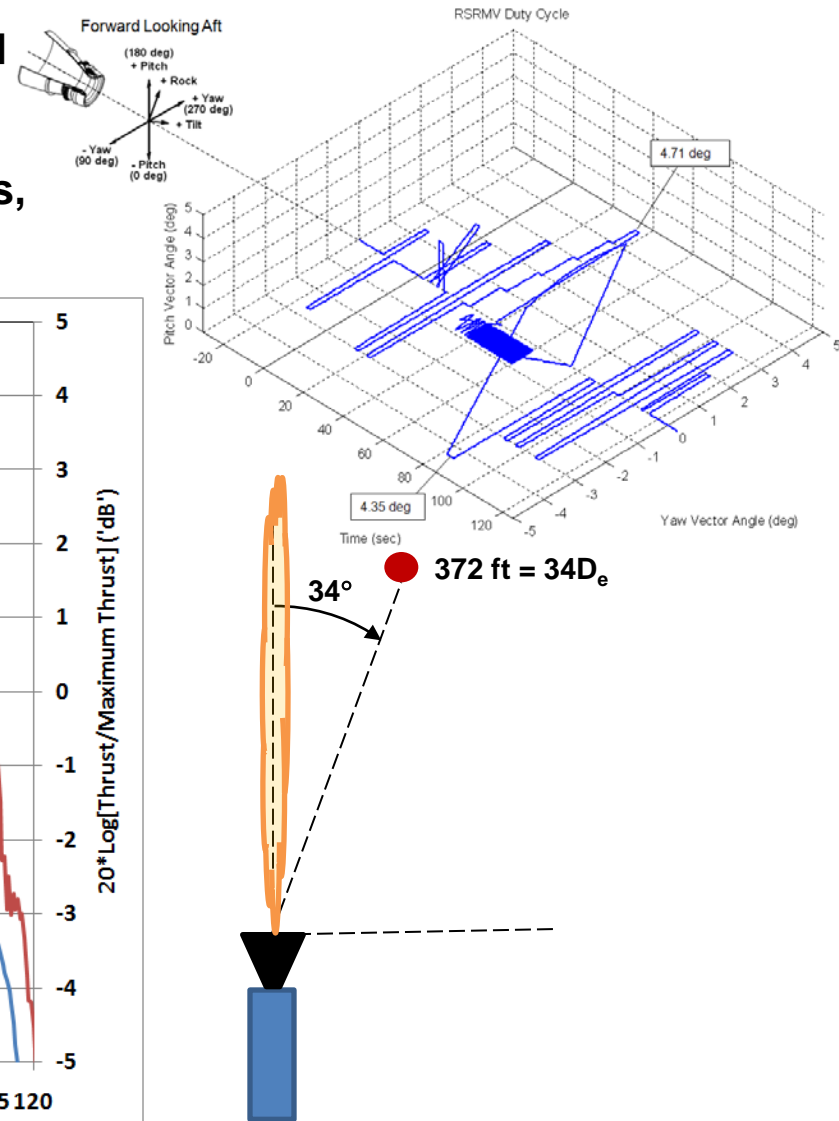
Local acoustics sensitive to changing plume source strengths from associated thrust changes

OASPLs do not roll-off as thrust does at end of burn; plume (and sound sources) retreat towards measurement



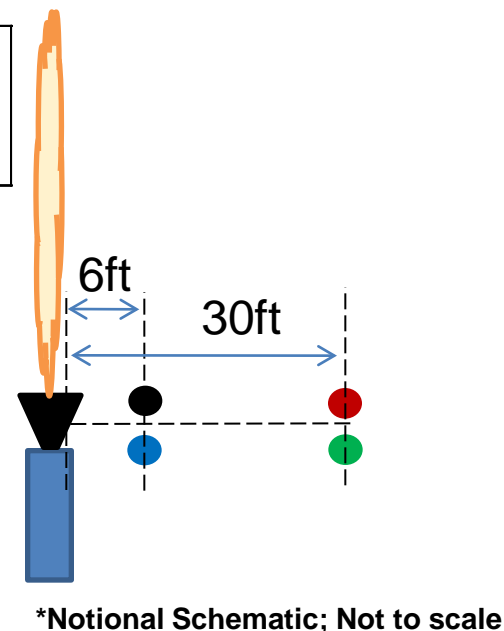
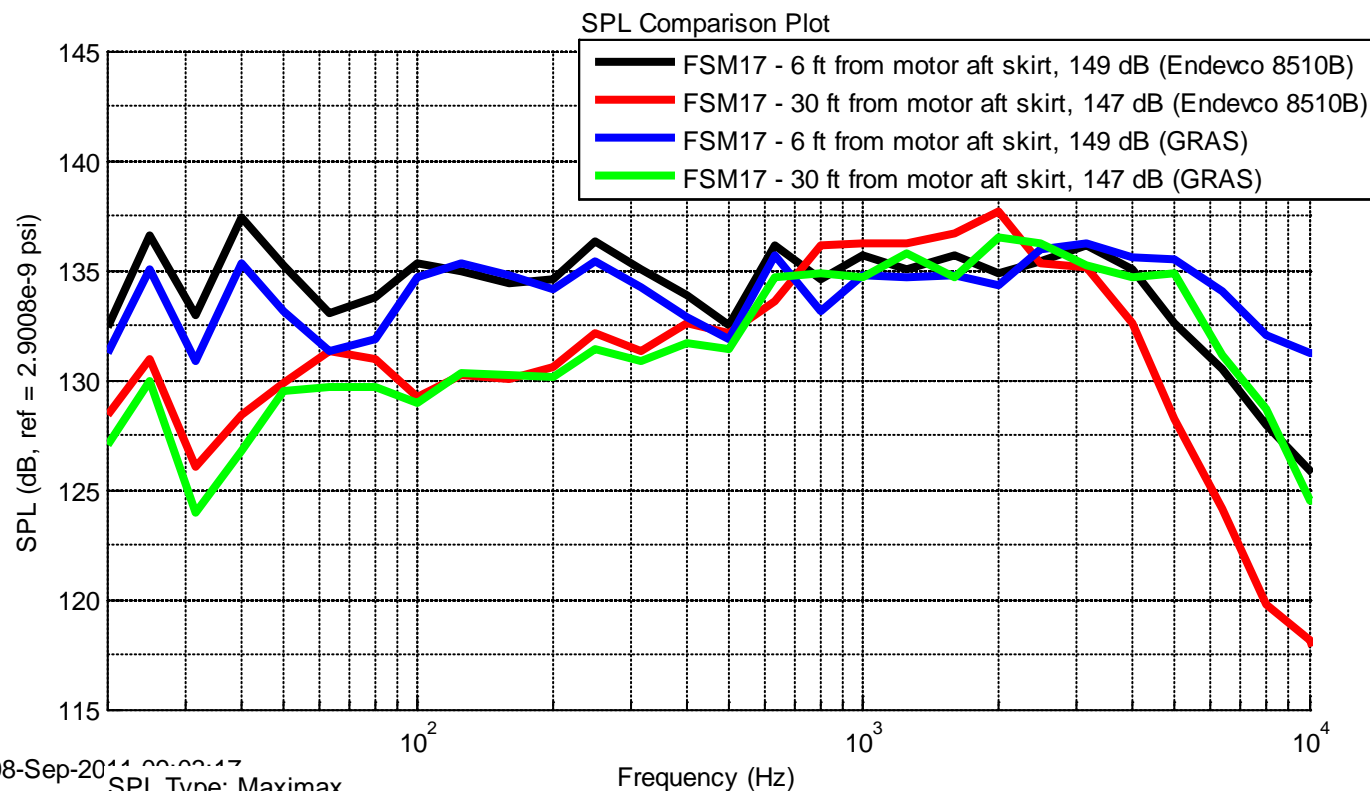
Duty Cycle effects more pronounced for the far-field measurements than on motor

Measurements closer to downstream plume sources, in particular around 75-80 sec



*Notional Schematic; Not to scale

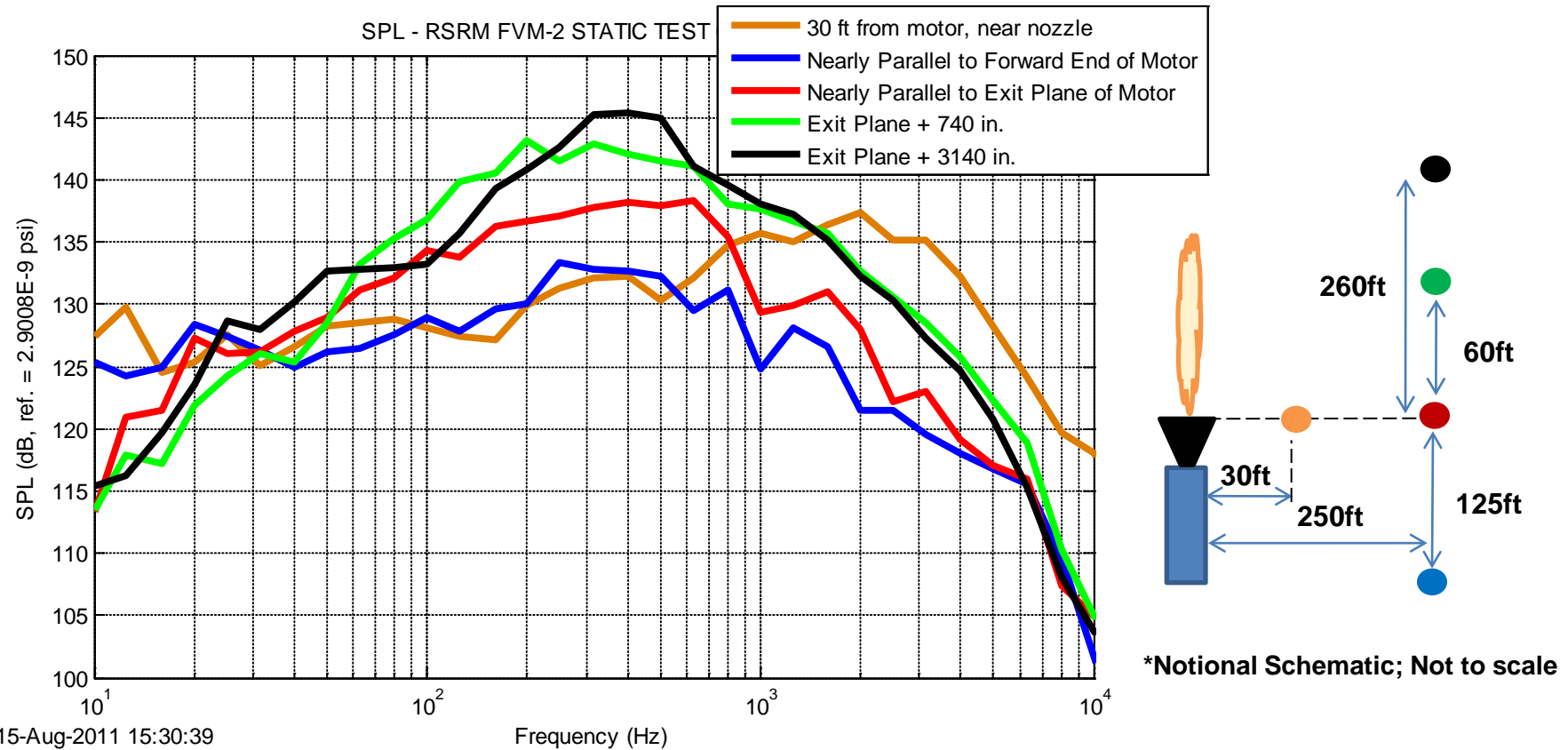
Comparisons for prior (Endevco) and current (GRAS) sensors for same locations



Acoustic energy more wideband at 6ft with no apparent spectral roll-off

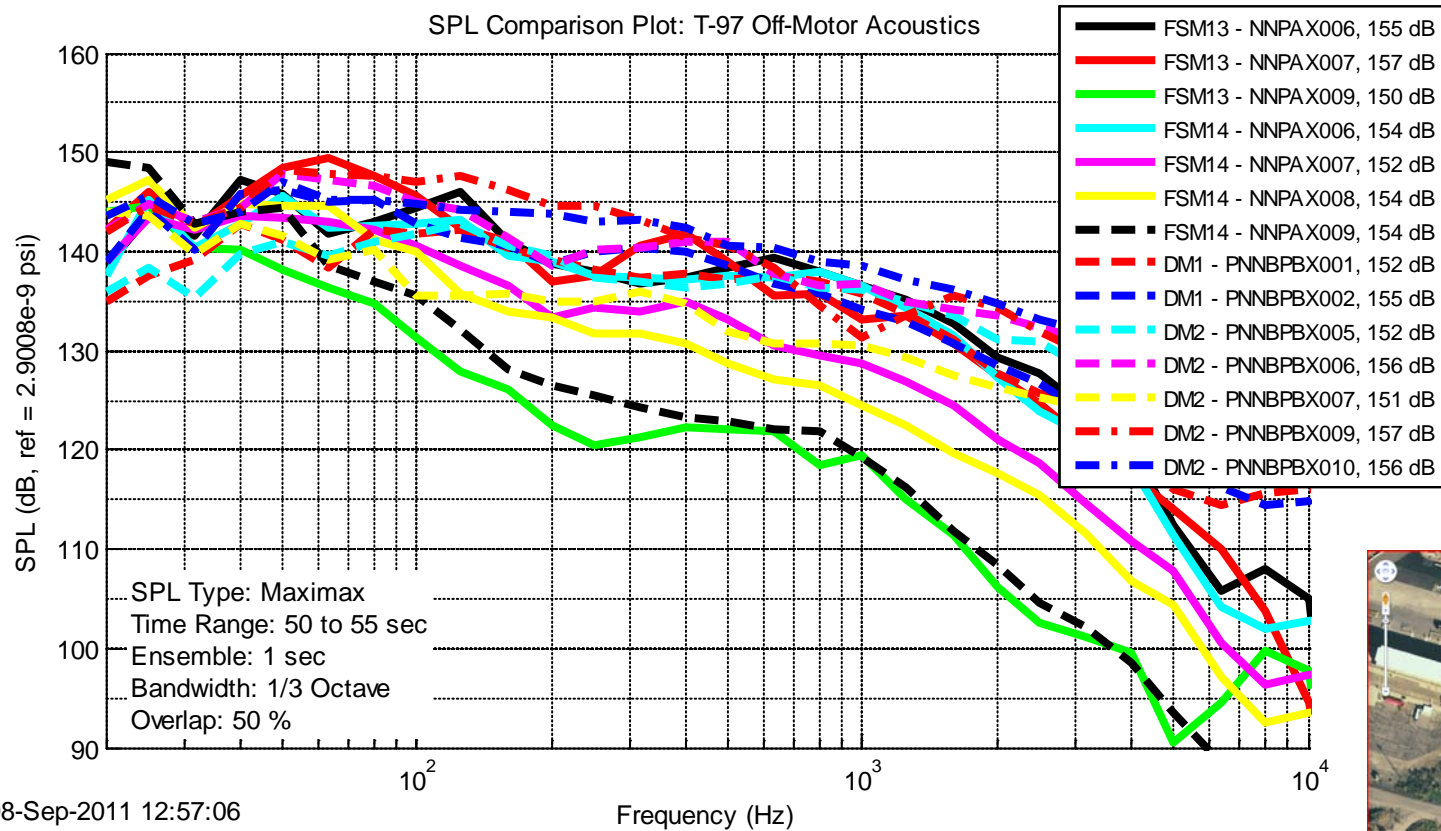
Acoustic energy peaks at 2000 Hz at 30ft with notable spectral changes at lower and higher frequencies

Difference is only 2 dB between measurement locations



Acoustic energy peak shifts from 2000 Hz down to 200 – 500 Hz by moving further away from the nozzle

Octave band SPL peak rises as one moves from motor location to downstream of nozzle



Majority of acoustic energy located below 100 Hz

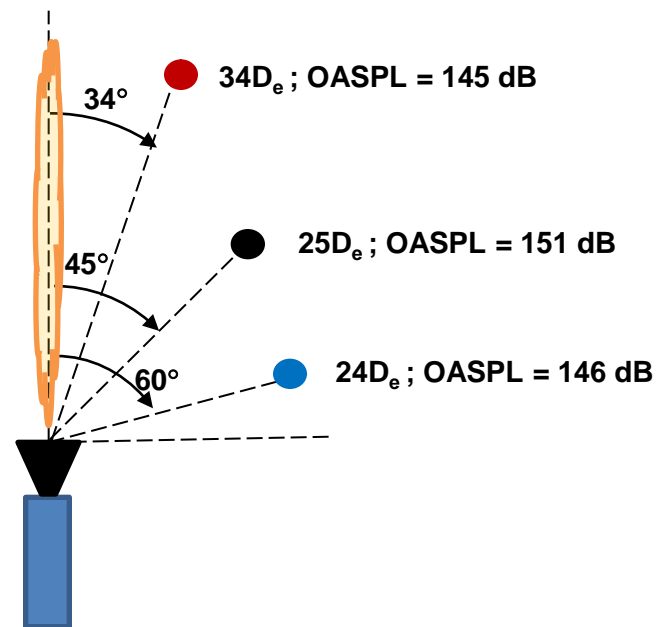
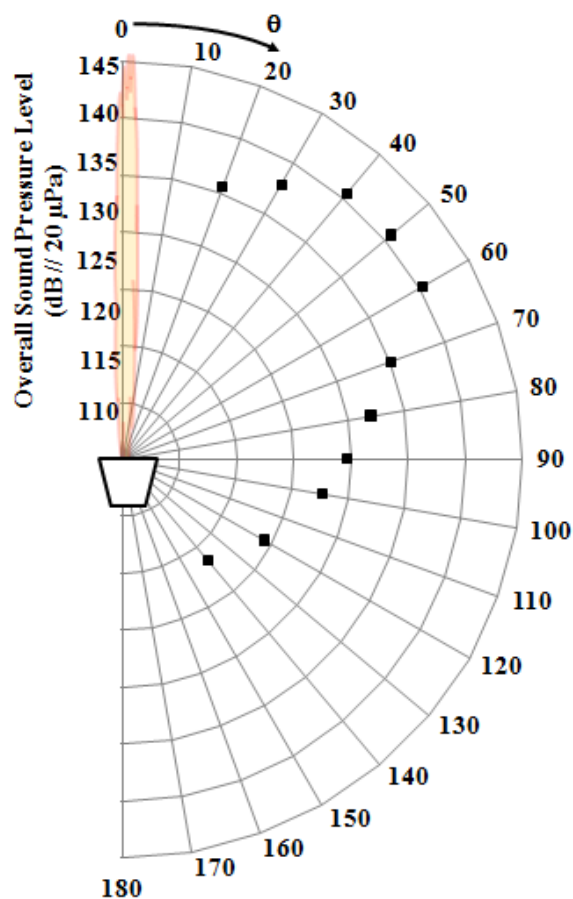
Spectral roll-off similar across different measurement locations and firings

Largest OASPL difference is 7 dB

Far-field vs. Near-field Directivity

Previous RSRM measurements had circular array at 79 nozzle diameters away from nozzle exit plane. Showed peak lobe occurs at approximately 50-deg throughout test

Recent RSRMV measurements indicate that OASPLs have directivity, but not enough data was collected to define the directivity pattern in the near-field



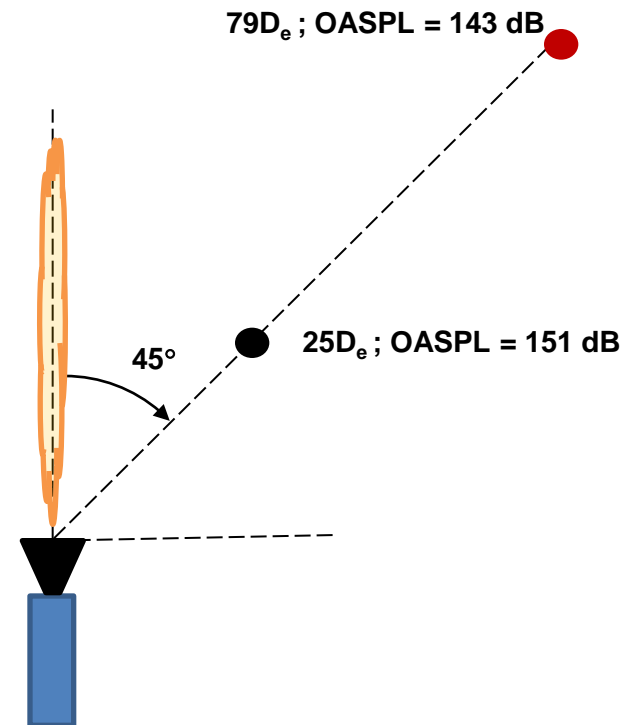
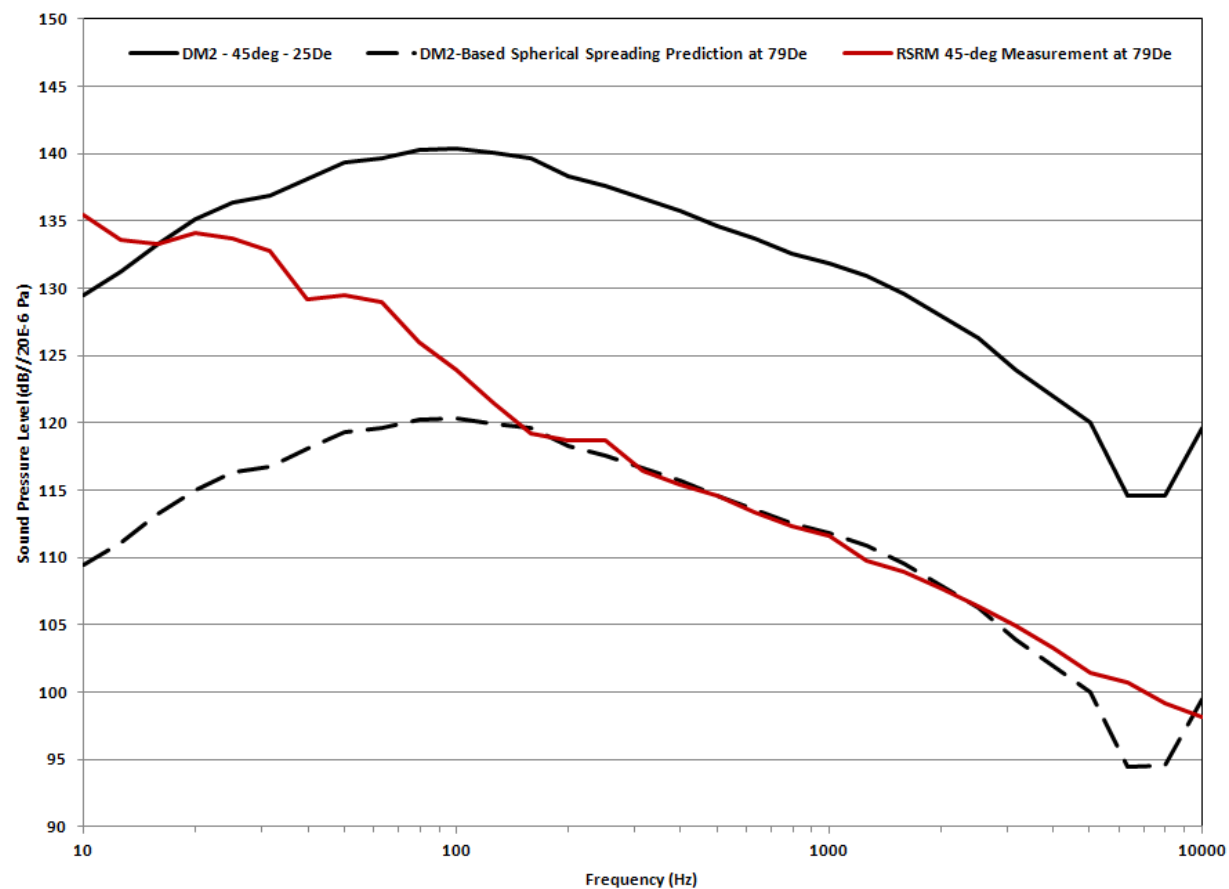
*Notional Schematic; Not to scale



Compared DM2 45deg spectra at $25D_e$ to the prior RSRM 45deg spectra at $79D_e$

Notably good agreement above 100 Hz to ~4000 Hz; poor comparison between 10 – 100 Hz

‘Far-field’ definition frequency dependant? Coincidence?





Significance of the work

Time histories continue to show positive skewness

Spectral shapes strongly dependant on measurement location relative to nozzle exit origin

No apparent differences in spectral characteristics between 4 and 5-segment motor acoustic measurements at similar locations

Motor operation, specifically changing thrust level, plume length, and nozzle angle all influence the acoustic measurements.

- Apparent plume source strengths and locations relative to the measurement define the acoustic results

Collected data useful for empirical inputs into non-linear / linear acoustic models

- Free-field measurements: plume source definition and acoustic propagation
- On-motor measurements: near-surface acoustic environment and transmitted sound through panels -> vibration models

*For more information about ATK's
test capabilities
Contact: Kevin Rees, Test Director
435.863.6471
Kevin.Rees@ATK.com*



Rocket motor testing

Structural testing

Environmental testing

Dynamic testing

**High reliability cable
manufacturing**

**Custom measurement &
transducer development**

**Control system design &
fabrication**

**Warhead development &
testing**





BACKUP

Reusable Solid Rocket Motor (RSRM)

Thrust and nozzle diameter comparable to current Ares I booster design

